# WB.3 Antenna-Coupled Millimeter-Wave $LiNbO_3$ Electro-Optic Modulator*

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The phase-velocity mismatch due to material dispersion in traveling-wave $LiNbO_3$ optical waveguide modulators may be greatly reduced by breaking the modulation transmission line into short segments and connecting each segment to its own surface antenna. The array of antennas is then illuminated by the modulation signal at an angle which produces a delay from antenna to antenna to match the optical waveguide's delay.

A phase modulator, 25 mm long with 5 dipole antenna/transmission-line elements, was operated from 4.3 to 13 GHz with a maximum phase modulation sensitivity of about 100 degrees/$\sqrt{\text{Watt}}$ (Figure 1). The optical wavelength was 633 nm. The expected variation of response with illumination angle was confirmed. A simple theory of antenna and transmission-line modulator behavior has been developed and matches the measured frequency response. This work was reported previously[1,2].

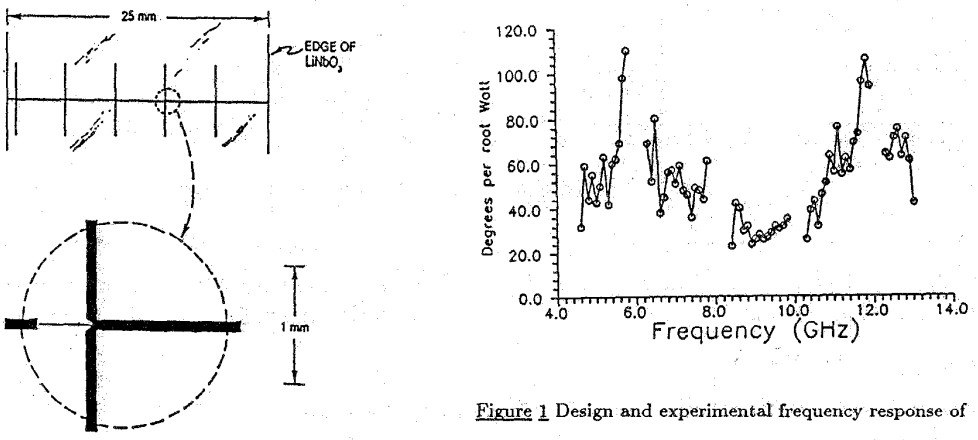


Figure 1 Design and experimental frequency response of the X-band prototype antenna-coupled modulator.

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A second phase modulator, 18 mm long with 20 antenna/transmission-line elements was operated at V-band and had a maximum phase modulation sensitivity of approximately 80 degrees/$\sqrt{\text{Watt}}$. This showed that the modulator design can be scaled for mm-wave operation quite successfully (Figure 2). This second modulator was designed simply by scaling the antenna/transmission-line elements of the X-band modulator by a factor of six. Of course, many more elements were needed to cover the interaction length.

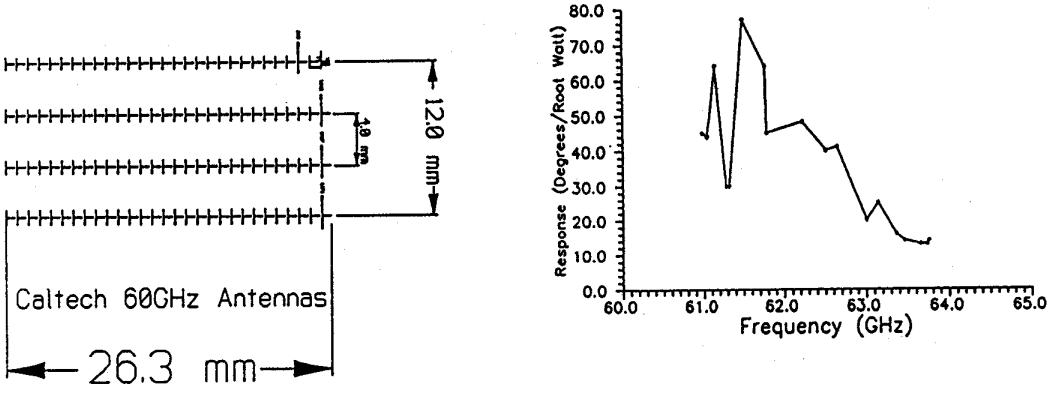


Figure 2 **Mask design and experimental results of the V-band prototype phase modulator.**

A third modulator, using broad-band bow-tie antennas and designed for W-band operation, is being fabricated at the time of writing. This modulator is to be operated as a Mach-Zehnder amplitude modulator. A Mach-Zehnder modulator requires use of dc bias to set the unmodulated phase-difference between the optical paths to $\pi/2$. This cannot be done with dipole antennas, but bow-tie antennas are insensitive to dc connections made to the ends of the antennas. Results obtained with this modulator will be presented.

References

[1] William B. Bridges, Finbar T. Sheehy and James H. Schaffner, "Wave-Coupled $LiNbO_3$ Electro-Optic Modulator for Microwave and Millimeter-Wave Modulation,": to be published in Photonics Technology Letters, Feb. 1991

[2] –, "Velocity-Matched Electro-Optic Modulator," SPIE Vol. 1371 High Frequency Analog Fiber Optic Systems (1990) pp. 68-77, San Jose, California, September 1990